Appl Water Sci (2017) 7:349–359
DOI 10.1007/s13201-014-0250-2

ORIGINAL ARTICLE

Water wells' exploitation and its impact on the drying up of foggaras

The case of the foggara of M'ghaer, Timimoune, District of Adrar, Algeria

Bensaada Mohamed · Boualem Remini

Received: 29 April 2014 / Accepted: 27 October 2014 / Published online: 18 December 2014

Abstract For a long time, man had to explore groundwater by constructing special hydraulic works. Thus, in ancient times, hydraulic civilizations such as the *foggaras* in Iran, Egypt, China and Latin America were born. In the Algerian Sahara, the *foggara* has played a leading role in the field of abstraction of groundwater distribution and sharing through formal and strict rules. Today, this technique has been disappearing and drying up. This decline does not only increase year by year, there were over a thousand *foggaras* in the early 1960s, but today only 915 *foggaras* have been listed for all those regions. Among the factors favoring the decline of *foggara* is the exploitation of water by deep holes drilled near the latter. In this article, we try to show the impact of drilling on the *foggara.*

Keywords *Foggara* of *M'ghaer* · Timimoune · Aquifer · Drying up

Introduction

The space occupied by the population along the Algerian Sahara has been at the origin of the installation of underground tunnels that drain the water table using a regular slope lower than the general slope of the ground, known as the *foggaras.*

The *foggara* is a traditional irrigation system used in the oases of Adrar and Timimoune for more than ten centuries. It consists of an underground tunnel draining water from the water reserve to the fields to be irrigated. The *foggara* has been used in more than 30 countries (Hofman 2007) and given different names: *kariz* or *karez* in Iran (Goblot 1979), *khettaras* in Morocco (Lightfoot 1996a, b) and *kareses* in Afghanistan (Hussain et al. 2008).

These concepts and methods have been developed over a long period over the centuries, allowing man to live in these hostile regions by developing and improving these traditional harvesting techniques and management.

The economy of the latter is based mainly on agriculture and this, of course, is conditioned by water. This ancestral hydraulic system gave a peculiar physiognomy to the economic life of the palm; it is a difficult and expensive means of irrigation.

The construction of a *foggara* is a collective work; the establishment of this system of distribution has led local people to develop through the centuries, organizational, technical and legal water catchment with very elaborate water management and structures.

This management system was strongly influenced by social, cultural and geographical segments of the region. Each individual becomes the owner of one part water, or to financial expenses occasioned, either by participating in the construction or extension of a *foggara*.

The development of modern agriculture in the region entailed large exploitation, single-crop agriculture and deep well irrigation. This energy- and capital-consuming system has caused a dwindling of the water reserve and thus a decrease in the flow of some *foggaras*.

B. Mohamed (✉)
Branch from the Post-graduation and Scientific Research, Superior National Agricultural School, El Harrach, Algiers, Algeria
e-mail: m_bensaadadz@yahoo.fr

B. Remini
Department of Water Sciences and of Environment, University of Blida, 9000 Blida District, Algeria

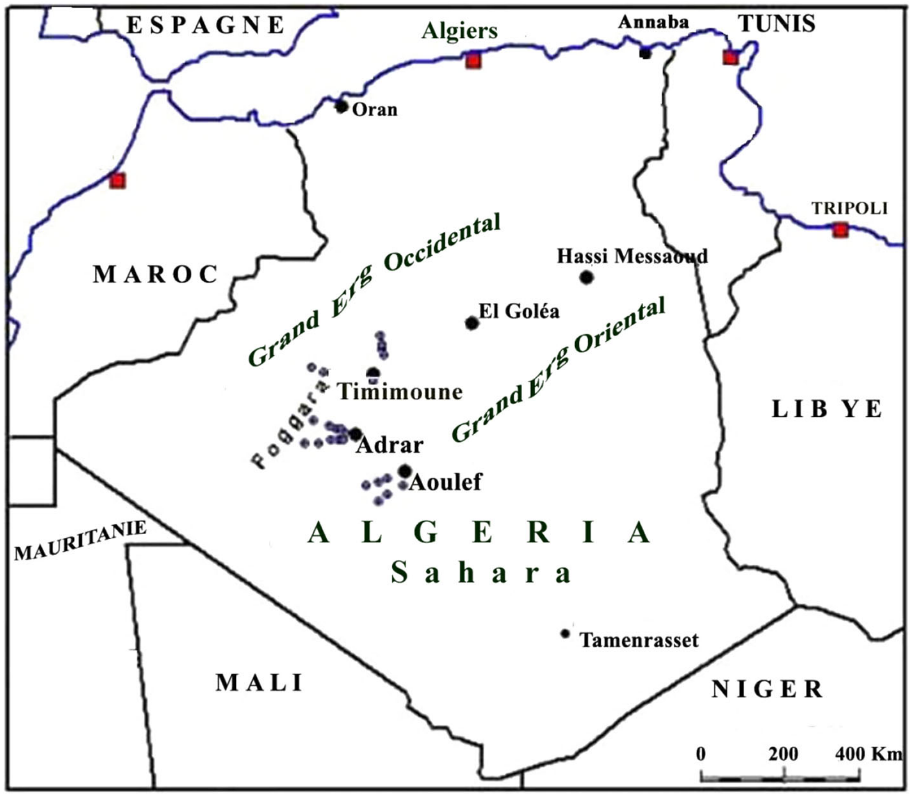


Fig. 1 Geographical situation of the studied area

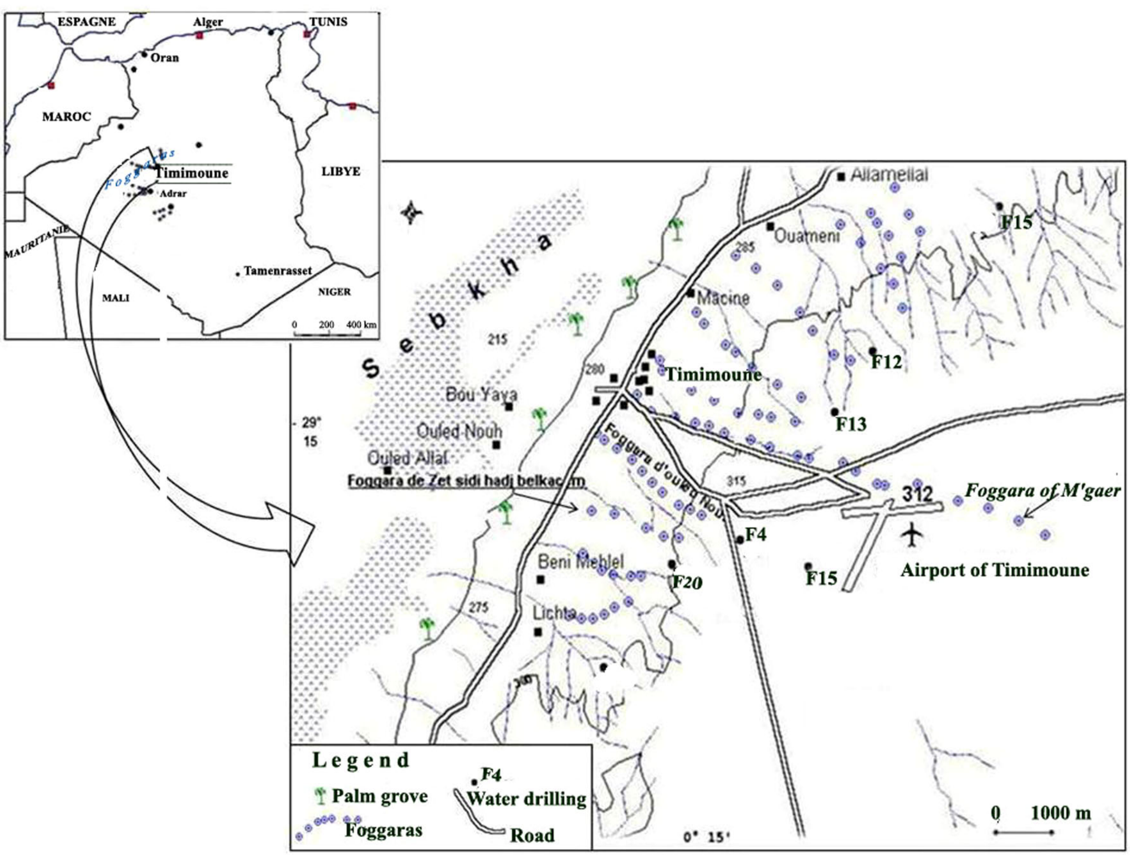
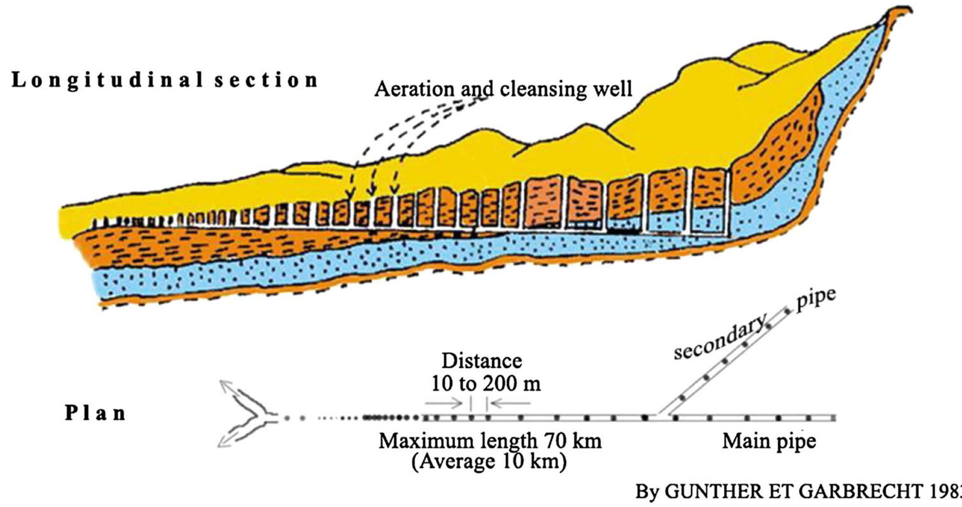


Fig. 2 Geographical situation of the *foggara* of *M'ghaer*

Fig. 3 A schematic sectional foggara



The geographical situation of the studied area

The oasis of Timimoune is located in the southwest of Central Algerian Sahara more than 1,000 km off Algiers (Fig. 1). The area is arid and water is rare. That is why the oasis inhabitants exploit underground water without using electric energy by means of the *foggara* system.

The region offers a variety of morphological forms. It consists of sandstone plateaus and terraces; the lower areas are occupied by *sebkhas* and the north and east contain large surfaces covered by dunes (Erg).

The studied area is characterized by a hyperarid climate with high evapotranspiration. Precipitation is rare and usually small with variable quantitative importance from 1 year to another. The average monthly rainfall ranges from 0 mm in July and 3.6 mm in October, and the annual rainfall is 10 mm/year Dubief (1959). The winds are very unpleasant; the maximum number of prevailing winds are from the north east who are responsible for blowing sand. Evaporation greatly exceeds precipitation.

The dry period from June to September has a zero contribution to storm. The coldest month is January (12 °C–16 °C) and the warmest month is July (36 °C–49 °C).

The climatic conditions are harsh including scarcity of rain, intense sunshine, high evaporation, dry air and blowing sand.

Presentation of the *foggara* of *M'ghaer*

The *foggara* of *M'ghaer* is located between east longitude (00° 13′ 09″) and north latitude (29° 15′ 34″) (Fig. 2). It consists of a draining tunnel between 70 and 100 cm wide, with the height of a curved man and a series of 380 wells 3–9 m apart.

It is the biggest *foggara* in the region of Timimoune, constructed at an unknown time. It might have been developed by Saint Sidi-Othmane and his son who lived in the ninth century of Hegira (Islamic calendar), i.e., 450 years ago (PNUD 1980).

The concept of a *foggara*

The *foggara* is a slightly tilted underground tunnel with water flowing downstream due to gravity to a topographic area relatively lower than the piezometric surface.

It consists of a series of wells 3–12 m apart and a tunnel 50–80 cm wide and 90–150 cm high.

The wells have no hydraulic function; they helped in the digging of the *foggara* and serve presently as air vents (chimneys) and as observation manholes for the tunnel. They help as well in the upkeep, cleansing and removal of sand (Fig. 3).

A *foggara* may consist of about 500–600 wells; these wells are 3–4 m deep at the start of the village, reaching 30–40 m in the heights of some *foggaras*, as that of *M'ghaer* whose uppermost well is 40 m deep.

All *foggaras* are parallel and have almost the same direction; they maintain some distance in between, so as to avoid severe drainage at the expense of neighboring and more ancient *foggaras.*

The digging out of a *foggara* is only possible when the ceiling of the water reserve is higher than the areas to be supplied. The upstream part of the *foggara* penetrates the water reserve, whereas the downstream part supplies water to the palm groves.

The hydraulic works of a *foggara*

The construction of these works aims at distributing and sharing water according to a traditional social organization.

Every beneficiary continually receives his due. The sharing of water is carried out by a system of combs set up in every *Kasria* according to an ancestral customary rule. Every family canalizes its share of water to their garden by means of a system of canals called *séguias.*

This ancient system enables a lasting management of the works and a fair distribution of the water resources between all inhabitants of the *Ksar*.

The main Kasria

At the exit end of the *foggara* (Photos 1, 2), water is carried to a triangular basin called the main *Kasria*. It is blocked by a comb-shaped divider made of a soft and easily chiseled stone, serving as a water stabilizer. This comb, also called *mocht*, is provided with a sufficient number of openings so that water does not flow back.

Photo 1 Exit end of the *foggara* of *M'ghaer*

Photo 2 Main *Kasria*

This technique serves to calm the water prior to its distribution; it is a kind of a hydraulic tranquilizer.

The main *Kasria* distributes the flow of the *foggara* into three, four or five big channels called *majari* (plural of *majra*).

From this basin, the canals stream in all directions toward the tracts of land to be irrigated. At the end of these *majari*, other secondary *Kasria* allow water to flow into canals that might be divided anew by another comb toward the gardens of the palm grove also called *guemmoun* (Photos 3, 4).

Photo 3 Guemoun

Photo 4 Palm grove

The secondary Kasria

It is a new and equally important basin found after the first one and serves to share water between the families and tribes that participated in the construction of the *foggara* (Photo 5).

Photo 5 Secondary *Kasria*

At several levels of the palm grove, water is yet again divided by other combs and led toward the tracts by smaller canals (Photos 5, 6). The canals proceed as a very dense distribution network that ends in a collection pond called *madjen.*

Photo 6 Canal

The madjen

It is a shallow recovery and regulation pond, sometimes rectangular, located in the highest spot of the garden where water is to be collected for 24 h.

The irrigation is generally carried out very early in the morning in summer and at late morning in winter. Every garden has a *madjen* made of clay or concrete to avoid waste (Photo 7).

Photo 7 *Madjen*

A geological and hydro-geological overview of the study area

Geologically, the area is formed by a Continental Intercalary just beneath the surface of a large part of the region and represents the main aquifer with interstice porosity. It is characterized by considerable heterogeneity (sandstone, sand and clay) and by a variable power, diminishing from east to west (680 to 240 m). This horizon bevels near Tademait Plateau which is located to the west of the study area.

The hydro-geological study shows that the Sahara is one of the largest deserts in the world, being a sedimentary basin that extends over 780.000 km^2.

The underground water flows mainly from NE to SW and generally converges toward the *foggaras* of Timimoune, Adrar and Reggan (Fig. 4).

In the region of Timimoune and Adrar, water starts to flow from East to West.

The aquifer is mainly supplied by the infiltration of streaming water from the southern side of the Saharan Atlas and from the edges of the Tademait Plateau.

The geology of Timimoune is basically made up by shales overcome by soft sandstone, sometimes harsh conglomeratic level. Into surface the sandstones have a stratification cross bedding, by going to the airport, into the upstream of *foggaras M'ghaer* the rock consists of a quartzitic slab (Fig. 5).

The establishment of a hydrogeological section passing through the *foggaras* of *M'ghaer* shows that the geology is constituted by the intercalary Continental (Fig. 6).

Establishment of a hydrogeological section passing through the *foggara*s of *M'ghaer* show that the geology is constituted by the intercalary Continental, lithostratigraphy is formed by a heterogeneous sandstone facies, sands, clays and gravels.

The Hydraulics of the wells neighboring the *foggara* of *M'ghaer*

In order to determine the interference between the wells and the *foggaras*, we refer to the data collected from the well (F_4), (c.f Table 1).

The interpretation of the results of the test sheet by one level of long-term led us to calculate the radius of influence or the range of the well by applying the Law of Dupuit and the law of log–log approximation by C.E. Jacob.

The graphic interpretation of trial pumping

The execution and interpretation of the measured data (c.f Table 2), reduction and time have been based on Dupuit's formula and that of C.E. Jacob on the expression of underground hydrodynamics.

Supposing that the system is permanent, the drawdown of a well with r_0 radius is given by Dupuit formula:

$$\Delta_{r_0} = \frac{Q}{2\pi T} \times \text{Log} \frac{R}{r_0^2}$$

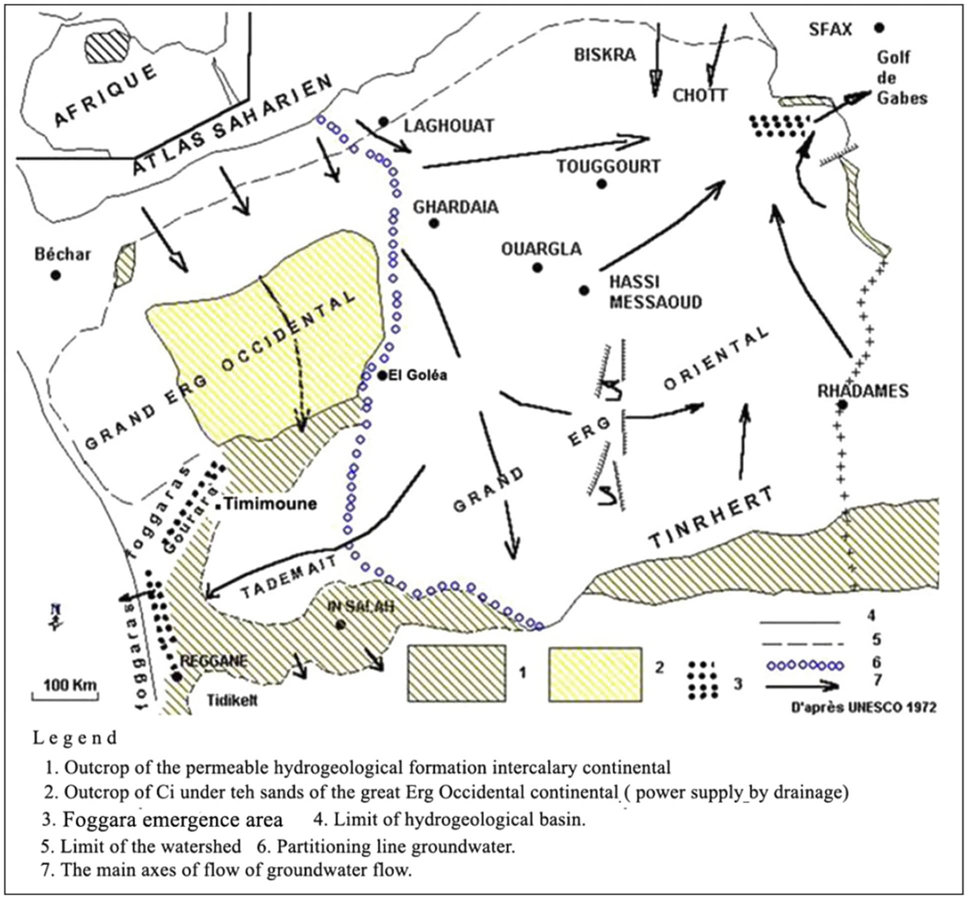


Fig. 4 Hydro-geological map of Algerian Sahara

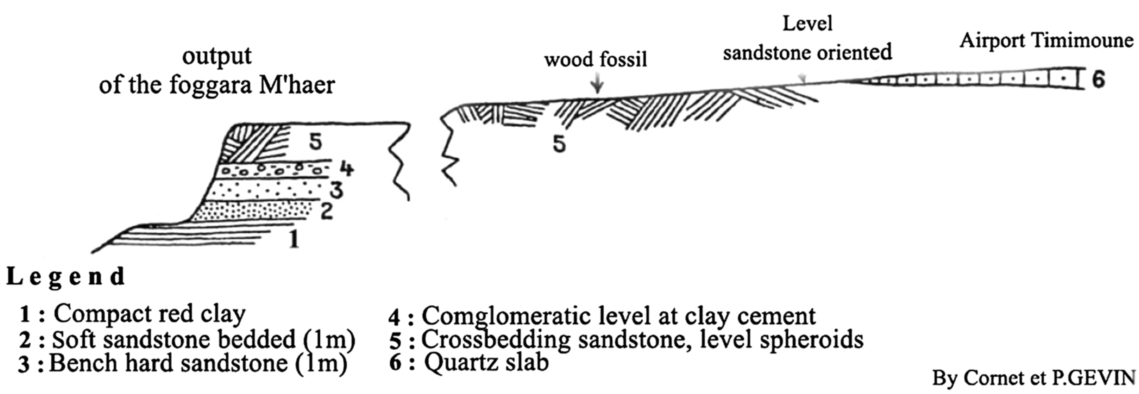


Fig. 5 Lithostratigraphics formations of the studied sector

Given that:

Δ_{r_0}: The drawdown measured in the pumping work in meters

Q: The constant pumping rate in (m3/s)

T: Transmissivity in m^2/s

t: The pumping time, in seconds

r_0: The radius of the pumping well in meters

R: The well range in meters

In the case of a non-re-fed underground water reserve by drainance or by a boundary, one can express the range of the wells depending on pumping time, by applying Jacob's logarithmic approximation to the well itself:

$$\Delta_{r_0} = \frac{Q}{4\pi T}\ \text{Log}\ \frac{2.25Tt}{r_0^2 S} = \frac{Q}{2\pi T}\ \text{Log}\ \frac{\sqrt{Tt/S}}{r_0}$$

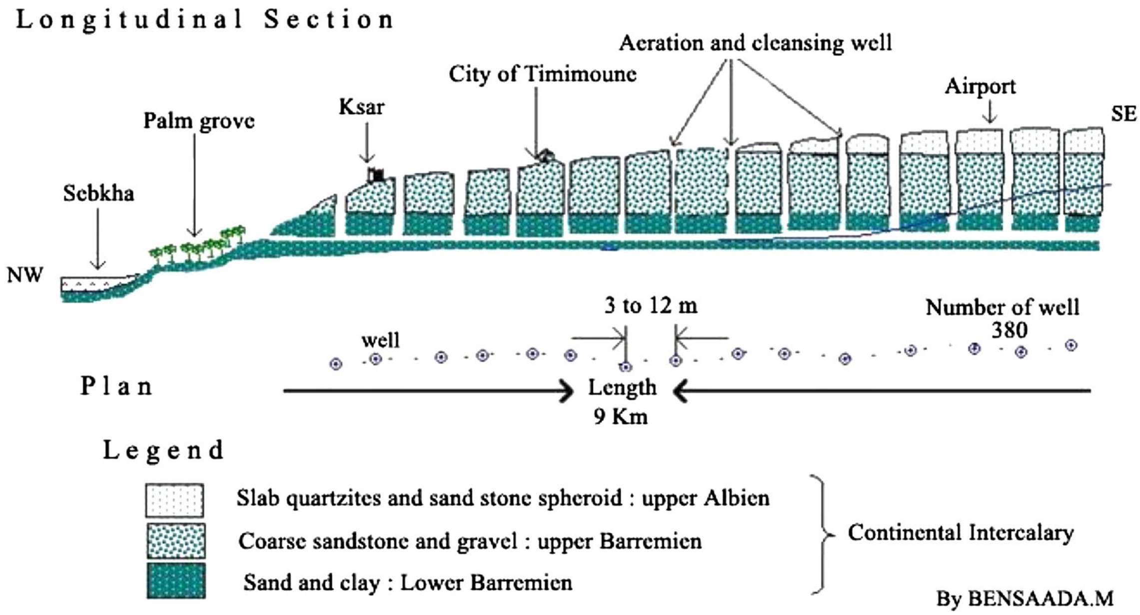


Fig. 6 Hydrogeological section of the *foggara* of *M'ghaer*

And comparing this expression to the Dupuit formula, one draws:

$$R = 1.5\sqrt{\frac{T \times t}{S}}$$

Given that S: is the storage coefficient, without unit of measurement

The tracing of the descent of the water drilling (F_4)

By putting the well level drawdown values on (y) axis in meters and pumping time values in seconds on the (x) axis, the graph result gives a representative straight line of which we determine the slope C [$C = \Delta_2 - \Delta_1$] and the storage coefficient is obtained by numerical calculation in the second term of the expression of Jacob:

$$T = \frac{0.079Q}{C} \qquad S = \frac{2.25Tt_0}{r_0^2}$$

The value of the range shows a clear influence on the *foggara* of *Ouled Nouh*, which is now dried, and a decrease in the flow of *the foggara* of *M'ghaer* (Fig. 7).

$T = 1.79.10^{-3}$ m^2/s et $S = 0.008$

Or $R = 1.5\sqrt{\frac{T \times t}{S}} = 295.5$ m

The well's impact on the *foggara*

The obtained values for the influence radius for well (F_4) can be applied on well (F_{13}) due to the fact that we are dealing with the same aquifer (continental intercalary), and that shows the direct impact of the latter on *the foggara* of *M'ghaer* (Fig. 8), i.e., a clear decrease of the flow and wasting away of vegetation because of the lack of water (Photo 8a, b).

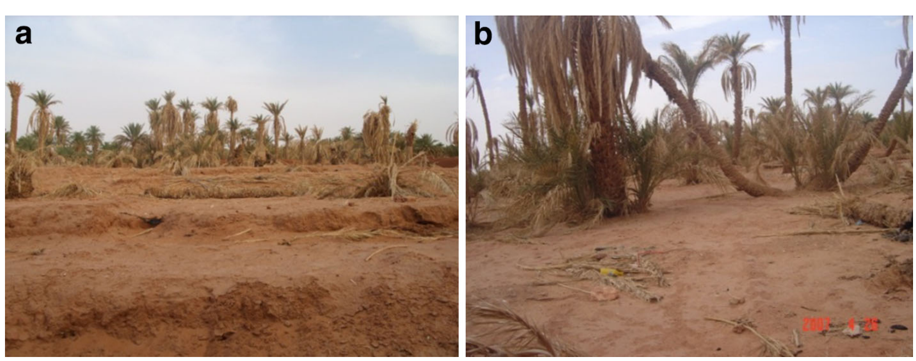


Photo 8 Gardens withering due to the drying up of some seguias

Table 1 Lithostratigraphic and technical log of drilling F_4

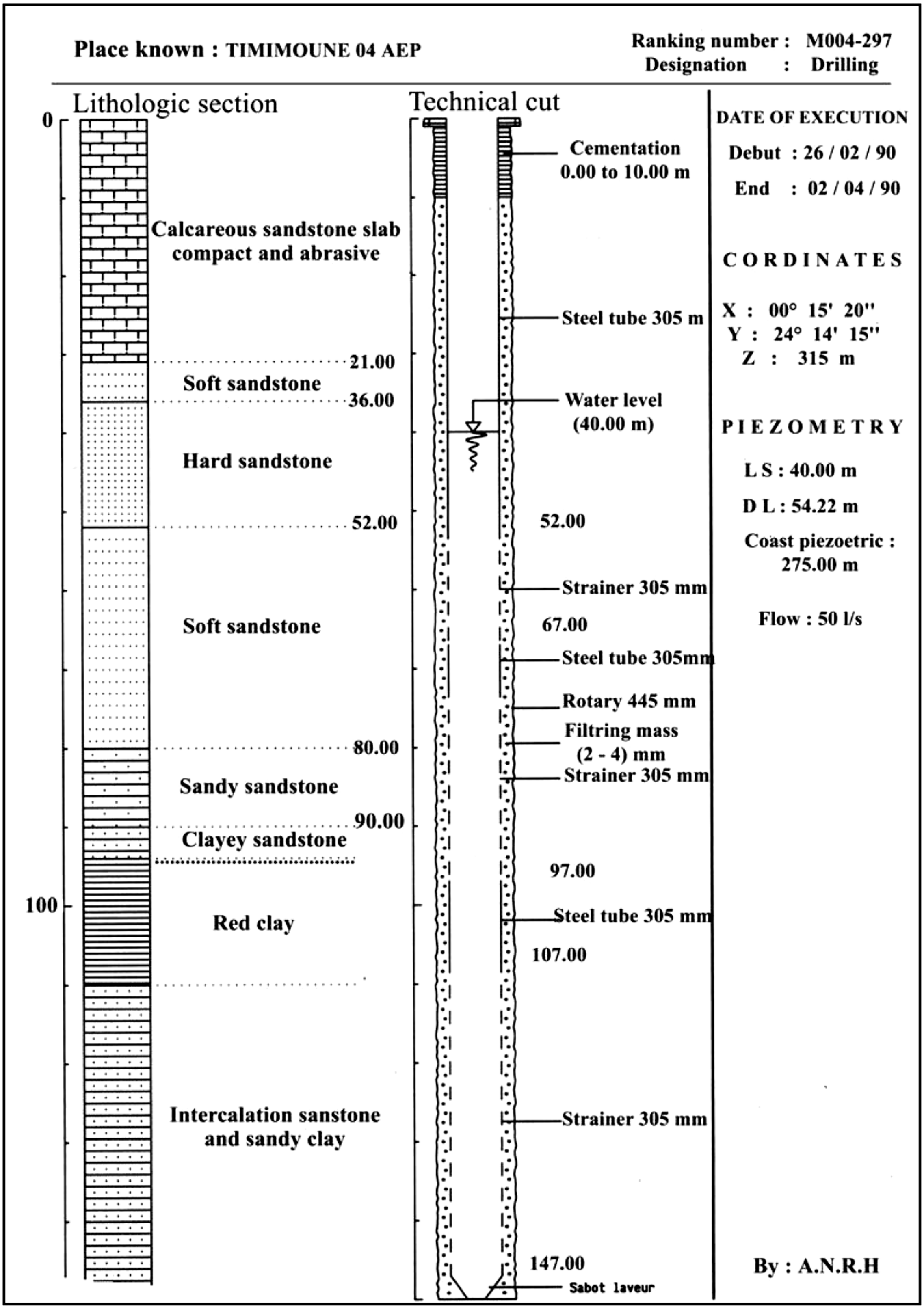


Table 2 Pumping well test F_4

t (s)	Δ (m)	t (s)	Δ (m)	t (s)	Δ (m)	t (s)	Δ (m)
0	0	1500	11.61	18000	13.35	68400	13.85
30	6.26	1800	11.86	19800	13.36	72000	13.94
60	7.36	2100	12.03	21600	13.46	75600	13.98
90	7.90	2400	11.99	23400	13.51	79200	14.00
120	8.31	2700	12.15	25200	13.56	82800	14.02
150	9.30	3000	12.21	27000	13.60	86400	14.04
180	9.56	3300	12.27	28800	13.64	93600	14.06
210	9.64	4200	12.33	30600	13.65	100800	14.07
240	9.70	4800	12.36	32400	13.67	108000	14.07
270	7.76	5400	12.41	34200	13.68	115200	14.08
300	9.80	6000	12.46	36000	13.69	122400	14.08
360	9.86	6600	12.52	37800	13.70	129600	14.08
420	10.11	7200	12.61	39600	13.70	136800	14.10
480	10.23	8100	12.81	41400	13.70	144000	14.09
540	10.34	9000	12.86	43200	13.71	151200	14.08
600	10.45	9900	12.96	46800	13.72	158400	14.08
720	10.49	10800	13.06	50400	13.73	165600	14.08
840	10.64	12000	13.11	54000	13.74	172800	14.08
960	10.70	13200	13.16	57600	13.75	ANRH ADRAR	
1080	10.82	14400	13.25	61200	13.78		
1200	11.13	16200	13.28	64800	13.82		

Data obtained through experimentation pumping descent constant; flow rate: 50 l/s. Well diameter: 12 inch. Pumping time is 48 h

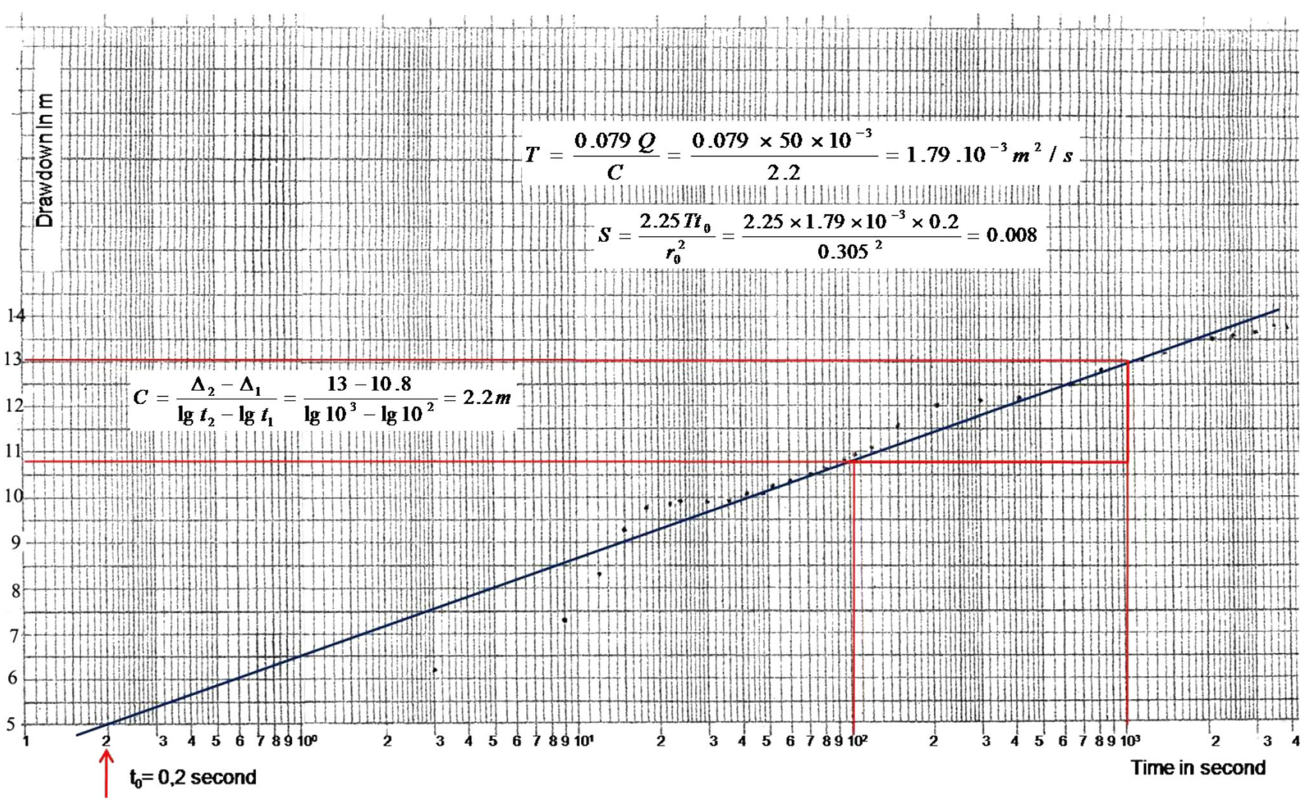


Fig. 7 Well's Descent Curve (F_4)

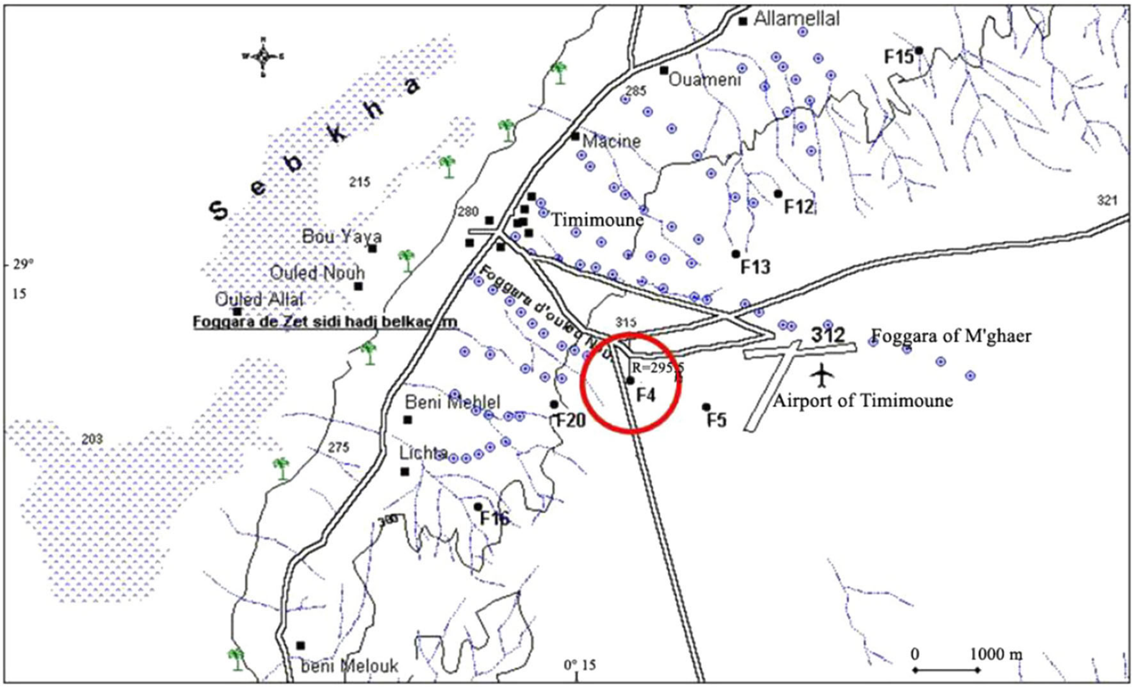


Fig. 8 Interference between wells and *foggaras*

Table 3 History of the flow of *foggara* of *M'ghaer*

Years	1998	1999	2000	2001	2002	203	2004	2005	2006	2007	2008	2009
Q. l/s	23	18	13	9	7	6.3	6	5	4.5	1	1	0.5

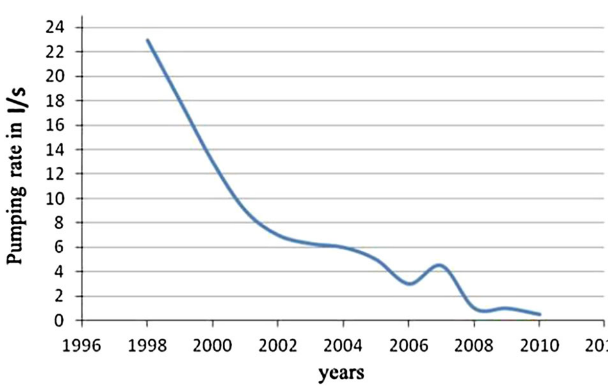


Fig. 9 Evolution of the flow of the *foggara* of *M'ghaer*

The follow-up of the difference in the *foggara's* flow between 1998 and 2009 shows a slow death of vegetation (Table 3).

It is noticeable that the sealing of the fields (proximity to the airport), the lack of maintenance and of skilled workforce have also contributed to the decrease of flow. A *foggara* needs a periodical maintenance and at least a yearly cleansing, but the cost thereof is considerably high and the know-how has not been handed down from generation to generation (Fig. 9).

Conclusions and recommendations

As has been shown above, drilling deep water wells near the *foggara* has a direct impact on it (due to the lowering of the piezometric level of the underground water reserve): the decrease of flow.

The construction of the *foggara* has taken a long time and thousands of unknown individuals in order to provide water to the inhabitants of this extremely arid area. The *foggaras* have been essential to the prosperity of some civilizations. In Iran for instance, they constituted the main water supply system. Water is a real property which requires a delicate way of distribution.

In order to save this hydraulic patrimony, we need to find a way that combines both old and modern techniques of underground water channeling.

In order to save this universal patrimony, the exploitation of the wells must be efficiently carried out so as to avoid interference with the *foggaras*. To do this, it is essential to diminish the pump flow, to cleanse the *foggara* regularly, and not to waterproof the areas surrounding the centuries old tunnels.

Bibliography

Bensaada M (2001) Study of hydraulic *foggara* of *M'gaer* (Timimoun) MA dissertation University of Blida

Cornet A, Gevin P (1948) Note d'hydrologie sur le gourara (ms.Archive S.C.H Alger)

Dubief J (1959) The climate of the Sahara. Institute of Meteorology and Physics of the Globe of Algeria, Algiers, in Idrotecneco (1982c)

Goblot H (1979) Qanats: a technique for acquiring water. Mouton, Paris

Gunther Garbrecht (1983) Les ouvrages hydrauliques des anciens: Les leçons de l'histoire. Revus d'impact n1: sciences et société, pp 5–17

Hofman A (2007) Traditional management of water qanat in Iran is compatible with the concept of IWRM? Synthesis technique, in February, Engref (Montpellier France), p 17

Honari M (1989) Qanats and human ecosystems in Iran. In: Beaumont P, Bonine M, McLachlan K (eds) Qanat, Kariz and Khattara: traditional water systems in the Middle East and North Africa. SOAS and Middle East and North African Studies Press, London, pp 61–85

Hussain I, Abu Rizaiza OS, Habib MA, Ashfq M (2008) Revitalising a traditional dryland water supply system: the karezes in Afghanistan, Iran, Pakistan and the Kingdom of Saudi Arabia. Water International, vol. 33. pp 333–349

Jacob CE (1944) Note on determining permeability by pumping test under water table conditions. US geological Surcev. Open File Report

Jacob CE (1947) Drawdown test to determine effective radius of artesian well. Transactions ASCE 112:1047–1064

Jacob CE (1963) The recovery method for determining the coefficient of transmissivity. In: Methods of determining permeability, transmissivity and drawndown. US Geological Surcey Water-Supply Paper 1536-I: pp 281–292

Lightfoot DR (1996a) Moroccan Khettara: traditional irrigation and progressive desiccation. Geoforum 27(2):261–273

Lightfoot DR (1996b) Syrian qanat romani: history, ecology, abandonment. J Arid Environ 33:321–336

Martinez-Santos P (2013) A priori mapping of historical water supply galleries based on archive records and sparse material remains. J Cult Herit doi: 10.1016/j.culher.2013.12.003

National Hydraulic Resources Agency (ANRH) (2006) Inventory of water drilling in the region Timimoune

PNUD (1980) The water and the Maghreb. An overview on the present, the heritage and future. pp 131–137

UNESCO (1972) Etude des ressources en eau du Sahara Septentrional, Rapport sur les résultats du Projet REG-100. UNESCO, Paris